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**CONTROL OF A 30 CM DIAMETER
MERCURY BOMBARDMENT THRUSTER**

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CONTROL OF A 30 CM DIAMETER MERCURY BOMBARDMENT THRUSTER

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Abstract

Increased thruster performance has made closed-loop automatic control more difficult than previously. Specifically, high permeance optics tend to make reliable recycling more difficult. Control logic functions were established for three automatic modes of operation of a 30-cm thruster using a power conditioner console with flight-like characteristics. The three modes provide (1) automatic startup to reach thermal stability, (2) steady-state closed-loop control, and (3) the reliable recycling of the high voltages following an arc breakdown to reestablish normal operation. Power supply impedance characteristics necessary for stable operation and the effect of the magnetic baffle on the reliable recycling was studied.

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Introduction

Recent improvements in thruster design have generally made closed-loop automatic control more difficult than for earlier thruster designs. The use of high permeance optics (refs. 1 and 2) has made the reliable cycling of the high voltage power supplies after a current overload difficult. The effect of a magnetic baffle (refs. 3, 4, and 5) on the reliable reapplication of high voltage must be determined. Recent changes in neutralizer operation (ref. 5) have necessitated a change in control logic, especially during periods of reduced beam current or high voltage breakdown. The start-up procedure developed, provides for the necessary heating of the mercury isolator and propellant feed system to achieve stable, steady state operation.

This paper details results of tests conducted to investigate these problems using a 30-cm diameter thruster with a power console designed and fabricated by Hughes Research Laboratories (ref. 5). This power console has dynamic responses which are characteristic of flight-type power conditioners and was specifically designed to operate a 2.75 kW thruster at beam current levels up to 2.0 amps.

The control logic used is that initially incorporated in the power console and generally described in references 7 and 8.

Apparatus and Procedure

Thruster System

The basic thruster used for these tests was a 30 cm diameter thruster described in references 5 and 7 and modified as described in reference 3. The ion extraction system used was a high permeance, compensated, dished grid system described in reference 2. The grids were dished to a depth of 2.29 cm and the compensation (ref. 1) was achieved by stretching the accelerator grid. The strain (elongation/unit length) was 0.35%. The cold gap spacing of the grids was typically 0.63 mm. This extraction system was capable of extracting beam currents greater than 2 amps at total accelerating

voltages of less than 1400 volts. The screen hole diameter was 1.91 mm with a fractional open area of 63% and a thickness of 0.38 mm. The accelerator hole diameter was 1.52 mm with an open area of 43% and a thickness of 0.76 mm. The thruster hollow cathode was 6.3 mm O.D. with a 0.76 mm diameter by 1.22 mm long orifice with a 45° half angle chamber to a depth of ~0.6 mm on the downstream surface.

The magnetic baffle coil (ref. 5) was an 8 turn aluminum ribbon. The mild steel baffle disk was 4.45 cm in diameter and was used in conjunction with a 7.6 cm diameter cathode pole piece.

The neutralizer subsystem was basically as described in reference 6. The cathode was 6.3 mm O.D. with a 0.38 mm diameter by 1.22 mm long orifice.

Both the neutralizer and cathode inserts were of rolled tantalum foil coated with barium carbonate mixture as described in reference 6 and positioned approximately 1.29 cm from the downstream face of the cathode.

The system was operated with mercury vapor isolators for thermal purposes only.

Power Conditioning System

The power conditioning console was initially designed and fabricated by Hughes Research Laboratories under contract NAS3-14104 (ref. 5).

The system block diagram is shown in Figure 1. The screen supply was constructed by series connecting the DC outputs of 8 high frequency (10 kHz) inverters. The discharge supply was configured with 3 series connected inverters and the accelerator supply was powered from a closed-loop line regulator. External capacitors, (0.5 MFD), were connected across the screen and accelerator supplies at the vacuum flange to insure stable recycling. Keeper, heater, and vaporizer power was supplied by a 5 kHz inverter. Each output used a magnetic amplifier to provide constant current control.

Major modifications made to this unit were in the areas of control and will be described later in the text. These changes resulted from high performance thruster operation and the use of high permeance ion extraction systems.

Instrumentation

All DC thruster operating parameters were measured by digital panel meters at the vacuum facility feed throughs. Voltages were measured directly and currents measured by using an appropriate shunt. All AC (5 kHz) voltages and currents were measured with the data system included in the power processing system. Analog signals, accurate within 10%, from the same data system were used for strip chart recording and continuous monitoring of data. All

oscilloscope traces were obtained using dual beam differential input oscilloscope and associated high voltage probes or current transformers. Rise times of this equipment was ~ 0.015 usec or less. The oscilloscopes were externally triggered from a common signal when an accurate time history of many parameters were needed.

Facility

All tests were conducted in a 1.2 m diameter bell jar on a 7.6 m diameter by 21.4 m long vacuum facility (ref. 9). The thruster was extended into the main chamber of the tank approximately 1 m beyond the tank wall during thruster operation to minimize ion beam-facility interactions. Bell-jar pressure was typically 5×10^{-6} torr and main tank pressure 2×10^{-7} torr during thruster operation.

Results and Discussion

Automatic Start-Up

To insure a fully automatic thruster start-up, it is necessary to establish an adequate thruster temperature distribution to insure stable operation, as well as the proper sequencing of power supplies to enable the system to transfer to stable steady-state closed-loop operation. The procedure described is one which fulfills these requirements. Time profile and power levels indicated, are not necessarily critical requirements and in fact, the optimum profile is very dependent on the specific thruster design.

The logic system employs digital counters for timing functions and comparators for sensing the state of a desired control parameter.

The start-up flow chart and time profile are shown in Figure 2(a) and (b) with symbols as defined in the symbol list. During the initial preheat phase of the start-up, power is applied to the heaters of the cathode, neutralizer, manifold isolator and the neutralizer vaporizer. The preheat time is set for ~ 32 minutes.

Upon completion of the preheat, three supplies; main vaporizer, cathode vaporizer, and discharge are turned on and an ignition potential of 1200 volts DC is applied to the neutralizer keeper. The neutralizer discharge is established at a preheat level of 2.5 A. When the neutralizer keeper current exceeds the comparator set value ($J_{NK} > 0.4$ amperes) the cathode keeper ignition potential (1200 volts DC) is switched on, subsequently establishing the keeper discharge at its preheat level of 1 A. The cathode keeper comparator set value is ~ 0.2 A.

When the cathode keeper current exceeds its comparator value, the cathode vaporizer is switched to proportional control with the discharge voltage, ΔV_I . Prior to establishing the emission current, J_E , the discharge voltage is the open circuit voltage of the discharge supply. The high discharge voltage commands the cathode vaporizer to maximum output. In addition, satisfaction of the cathode keeper comparator condition provides the start command for a decade counter. The completion of the decade counter sequence (~ 10 min.) and the appropriate neutralizer keeper current initiates the "high voltage on" command. Within this interval, the discharge

chamber current is established. When the emission current exceeds the J_E comparator set value (~ 4 amps) the cathode heater is turned off. At this point, the self-heating of the cathode due to the emission is sufficient to provide thermal stability.

Completion of the 10 minute interval permits the application of high voltage to the two grids, and switches the ion beam current/main vaporizer to closed-loop proportional control. Discharge emission current is then near its steady state operating value.

As the beam current increases and becomes greater than its comparator set value ($J_B \sim 0.5$ amps) a 3 second counter is started. At the termination of the 3 second interval a "thruster operating" command is generated. This command switches the keeper currents (J_{NK} and J_{KK}) to the desired steady state operating levels, (1.5 A and 0.5 A, respectively). The neutralizer heater and mainfold isolator heater are turned off, and the neutralizer vaporizer is switched to closed loop proportional control.

The given sequential control has provided reliable thruster start-up in the automatic mode. Sufficient time has been programmed into the sequence for the thruster to approach its thermally stable operating point.

Steady State Operation

Flow Rate Control

The prime requirement of long term steady state operation of a thruster system is achieved with 3 basic closed-loop proportional controllers, that govern flow rates to the main discharge chamber, the cathode and the neutralizer (refs. 7 and 8). The power supply/thruster closed-loop control is shown in Figure 3.

The beam current varies directly with the main flow rate. The proportional controller output determines the power to the vaporizer heater. Thus, if the beam current exceeds the controller reference set point, the controller output is decreased; if the beam is less than the reference, the output is increased. The cathode and neutralizer flow rates are voltage referenced controlled. The discharge voltage and neutralizer keeper voltage vary inversely with cathode and neutralizer flow rate, respectively. Subsequently a voltage greater than the reference will increase its respective flow rate.

Magnetic Baffle Current Effects

The effect of the magnetic baffle current on steady state operating characteristics was investigated. The initial magnetic baffle field of 55 ampere-turns was decreased incrementally. The discharge voltage was proportionally controlled to 37 volts by the cathode flow rate. At 32 ampere-turns the cathode vaporizer controller began cycling on and off, due to a steep discharge voltage/cathode flow characteristic in this region. The proportional controlled cathode vaporizer temperature oscillated about the steady state temperature with a time constant of several seconds. Figure 4 shows the controlled discharge voltage ($\Delta V_I = 37$ volts) at the higher magnetic baffle fields and the band

of oscillating discharge voltage (corresponding to the oscillating temperature) below 32 ampere-turns. As the magnetic baffle field was reduced to zero, the cathode flow requirement for a 37 volt ΔV_I operating point became so low that the discharge extinguished.

Note that the accelerator drain current increases and the beam current decreases as the baffle current is reduced to less than 32 ampere-turns, due to a "low mode" condition in which the beam current actually decreases with increasing main flow. Stable thruster operation was achieved for the same range of magnetic baffle currents if the cathode vaporizer was operated in manual mode. In this case, the cathode flow rate was not decreased by the proportional controller but remained nearly constant. The discharge voltage, however, did decrease with decreasing magnetic baffle current.

When the magnetic baffle field was reduced to 16 ampere-turns and less, an interaction between the power conditioner and its DC bus supply, (Fig. 1), was noted. Specifically, large amplitude oscillations of the source current were detected. Figure 5 shows an oscilloscope trace of the source current. Peak-to-peak amplitudes of the low frequency envelope (typically 8 msec period) exceeded 35 amperes at a DC operating level of ~ 12 amperes. During automatic thruster operation the amplitude of the source current oscillations was lower (~ 25 ampere peak-to-peak) and more periodic. The higher magnetic baffle field current ($J_{MBN} > 32$ ampere-turns) provides an adequate cathode flow rate. This interaction appears to be caused primarily by the low cathode flow rate resulting from the low magnetic baffle current when the cathode vaporizer is on proportional control.

Stable operation was achieved even at low magnetic baffle field current and low discharge voltage by manually holding the cathode flow rate constant.

Low Mode Detection and Correction

A very desirable feature for long term unintended operation of the thruster/power conditioner system is the ability to detect the main vaporizer low mode characteristic and return the control to the positive slope portion beam current/main propellant flow rate curve. An operational amplifier comparator was used to detect the accelerator drain current (J_A). The poor propellant utilization during low mode operation causes increased charge exchange ion production, increasing the accelerator drain current. A 10 ma accelerator drain current was indicative of low mode operation. If the accelerator current exceeds 10 ma at an otherwise normal operating condition, a logic command disables the main vaporizer power, reducing main flow. The comparator hysteresis of 4 ma together with the thermal time constant of the main vaporizer assembly allows the system to return to the positive slope portion of the curve.

High Voltage Recycle

High Voltage Supply Sequence

The most common perturbation to stable thruster operation is a high voltage power supply current

overload. When this occurs, the high voltages must be turned off and then reapplied in the proper sequence and at the proper rate to re-establish steady state operation. The sequencing and time rates are more critical when a high perveance grid system (refs. 1 and 2) is used. In addition, other supply operating points must be varied to prevent a subsequent arc when the high voltage is initially reapplied and to insure stable neutralizer operation in the absence of beam current. Time profiles presented here provided very reliable high voltage recycle following an arc.

High voltage trip 1 and 2 commands are generated by any of the conditions of Table 1. The high voltage trip 1 command reduces the high voltage to zero and provides commands to other supplies by generating the high voltage trip 2 command. The duration of the HV trip 1 command (or high voltage off time) was set for 3.6 seconds. This time was selected for convenience. However, it is felt that this time could be significantly reduced, if desired, without adversely affecting recycle reliability.

The most critical period in the recycle sequence occurs at completion of the high voltage trip 1 command when the high voltage supplies are again turned on.

It is imperative that the accelerator voltage always precede the screen voltage to prevent excessive electron back-streaming from the neutralizer to positive high voltage surfaces. Figure 6 illustrates the high voltage profile when the screen supply is turned on before the accelerator supply. The high voltage trip 1 command is completed at time equal zero and the screen supply was turned on. With no accelerator voltage to prevent electron back-streaming, the screen current exceeded 5 amperes and the internal overcurrent protection turned off the screen supply in ~ 20 msec. (The internal overcurrent detector turns off the supply when the current exceeds 5 ampere for several usec. It does not generate a high voltage trip command.) The accelerator supply was turned on 60 msec after the screen supply. It increases to its full value until the positive ion current drawn to the accelerator exceeds the criteria for a high voltage trip 1 and 2 condition. This generates a high voltage recycle command ~ 0.8 sec after the accelerator voltage was turned on. Such a condition can continue indefinitely as long as the screen supply precedes the accelerator supply turn on.

Figure 7 shows the properly sequenced reapplication of the accelerator and screen voltage which yielded reliable recycle, at a thruster beam current of 2 amperes. Note, that the accelerator supply precedes the screen supply, preventing excessive electron back-streaming.

It was found that the 60 millisecond delay time between the reapplication of the accelerator and screen voltages (shown in Fig. 7) provided reliable recycles. It is felt that the random variation in this delay time should be less than 5%.

The rate of change of voltage application can effect the recycle mode, even though the accelerator voltage precedes the screen voltage. A second high voltage arc could occur if the screen voltage increases to its steady state value more

rapidly than the accelerator voltage, since some minimum accelerator voltage is required to prevent electron backstreaming under all operating conditions (ref. 1). The rise time constants of the accelerator and screen supplies were 60 and 280 μ sec, respectively. No attempt was made to vary these parameters.

Discharge Chamber Operation During High Voltage Recycle

It has generally been found necessary to reduce the discharge plasma density during the reapplication of high voltage (ref. 5) in order to prevent a subsequent high voltage arc. The technique used was to decrease the emission current until after the high voltage has been turned on. Figure 8 shows the time profile for various thruster parameters during the high voltage recycle. The high voltage trip 2 command lasts for 4.8 seconds. Thus, the emission is restored to its run level 1.2 seconds after the reapplication of high voltage. Successful recycle was achieved for emission current levels from 1.5 to 4 amperes.

When the emission current is cut back, it becomes necessary to maintain adequate cathode heating. The cathode heater is turned on and the cathode keeper current is increased to approximately 1 ampere to partially compensate for the decrease in heating resulting from the reduced emission current level. As shown in Figure 8, the cathode heater current is kept on until the HV trip 2 command is completed. The cathode keeper current is maintained at the higher level until the "thruster operating" condition is fulfilled.

The mainfold heater on the engine body and the isolator heaters on the mercury vapor isolator flanges were arbitrarily increased to their preheat level until the "thruster operating" command was initiated.

The power dissipation in the thruster during the recycle is \sim 137 watts compared to \sim 359 watts during normal thruster operation.

Neutralizer Operation During High Voltage Recycle

During steady state operation, the minimum mass flow rate depends on the total neutralizer emission current. As the emission current decreases, operation at a low flow rate becomes exceedingly more difficult and the neutralizer will eventually extinguish (refs. 6 and 10). Thus, it is necessary to increase the neutralizer keeper current to partially compensate for the elimination of ion beam current neutralization during high voltage recycle. Figure 8 shows the neutralizer keeper current increased from 1.5 to 2.5 amp at the beginning of the high voltage trip sequence and returning to 1.5 amps upon receiving the "thruster operating" command.

In addition, it is desirable to maintain, or possibly even increase, the neutralizer temperature during high voltage off. This is accomplished further by increasing the neutralizer tip heater to its preheat level for the same period. The neutralizer vaporizer power is increased to its maximum until the "thruster operating" command is generated.

Vaporizer Control Logic During High Voltage Recycle

Several modes of controlling the main and cathode vaporizers during high voltage recycle (as shown in Fig. 8) were investigated. Figure 9(a) shows strip chart recordings of discharge voltage and beam current during a recycle when the vaporizers were left in closed loop control at the steady state run levels. The main vaporizer was driven full on when the breakdown was initiated and remained at that level until the beam current increased to greater than 1.95 A. This occurred when the emission current increased to its run level of 9.7 A at the completion of high voltage trip 2. The cathode vaporizer was driven to its minimum value (0 amps for Fig. 9(a)) in an attempt to maintain the 37.2 volt steady state level. The vaporizer remained at its minimum until the high voltage was reapplied at which point the discharge voltage was slightly greater than 37 volts and the emission current was 1.5 amps when the emission current was increased to 9.7 amps. When the emission voltage increased to 46.5 volts. As will be seen, it is this peak on the discharge voltage which is directly responsible for the large ion beam current overshoot.

The amount of discharge voltage overshoot is a function of the steady state cathode vaporizer current (i.e., initial vaporizer temperature) and the minimum vaporizer current during breakdown (i.e., the minimum vaporizer temperature attained during the recycle). The steady state cathode vaporizer current is determined by a variety of parameters such as magnetic baffle current. Tests were conducted to determine whether or not increasing the minimum cathode vaporizer current would significantly effect the discharge voltage overshoot. Even when the minimum vaporizer current was increased to 2.5 amps, no improvement was noted. The maximum ion beam current overshoot reduced to only 2.15 amps and the maximum discharge voltage decreased to 45.9 volts.

The cathode vaporizer controller was modified to maintain the vaporizer current within the controllable span throughout the breakdown. This was done by switching the controller reference or set point voltage from one analogous to \sim 37 volts to one analogous to \sim 34 volts, during the high voltage trip 2 period. This new set point was maintained until the switching of the emission current back to its steady state run level of 9.7 A (Fig. 9(b)). This reduced the discharge voltage maximum to 40.2 volts and the associated beam current peak to a maximum of 1.98 amps. The elimination of this large beam current overshoot greatly increased the reliability of the high voltage recycle sequence (especially in the case of multiple breakdowns) and is generally a more desirable operating mode.

A similar test was conducted at a lower discharge voltage and at beam currents of 1.95 and 1.2 amperes. The ion beam current and voltage responses are qualitatively the same as shown in Figure 10.

In the tests of Figure 11, the main vaporizer was operated in a manual control mode. Thus, the power to the vaporizer heater remained constant rather than increased during the recycle. The

discharge voltage/time characteristic was unchanged but the beam current approaches critical dampening and reaches its final value with no overshoot.

Magnetic Baffle Effect on High Voltage Recycle

It was not found necessary to reduce the magnetic baffle current from its steady state value for any stable thruster operation current. This was true at all beam current levels from 1.0 to 2.0 amps.

Impedance Effects on High Voltage Recycle

The effect of the 0.5 μ f capacitance on both screen and accelerator supplies was determined by removing these capacitors and relying entirely on the 0.25 μ f internal supply capacitance. Figure 12 shows recycle wave forms of the screen-accelerator voltage and current with no additional capacitance. Note, the large amplitude - high frequency impingement on the accelerator voltage and current. Figure 13 shows the same measurements but with the 0.5 microfarad capacitors across the vacuum feed-through connections. The current measurements were made between the 0.5 μ f capacitors and the power supplies. These traces are relatively smooth. Figure 14 shows the same current measurements made on the thruster side of the 0.5 μ f capacitors.

The capacitors were then placed at the immediate output of the power supply to check the effect of the cabling inductance of the 15 foot harness. No difference was found.

The breakdown and recycle time profile described above has provided reliable thruster operation during high voltage arc breakdowns. The control logic provides for removing the high voltage, reducing the discharge plasma density, maintaining adequate component temperatures, minimizing beam current overshoots and returning to closed loop control at a specified set point operation.

Three different thrusters of the same design were successfully operated for many hours with the established control logic.

Conclusion

Recent improvements in efficiency of a 30-cm thruster were achieved with discharge chamber and neutralizer redesign and the addition of a high perveance extraction system. The increased thruster performance has made both closed-loop automatic control and high voltage recycling more difficult.

Control logic functions were established for automatic thruster operation using a power conditioner console with flight-like characteristics. The control provided (1) automatic startup, (2) steady-state closed-loop control, and (3) the reliable recycling of the high voltages.

The automatic startup provides a sufficient thruster component temperature to insure stable operation, as well as the proper sequencing of power supplies to enable the system to transfer to stable steady-state closed-loop operation.

Long term steady-state operation is achieved with 3 basic closed-loop proportional controllers, that govern the thruster flow rates.

A common perturbation of a stable operating thruster is a high voltage arc. When this occurs, the high voltages must be turned off and then re-applied in the proper sequence and at the proper rate to re-establish steady-state operation. Concurrent to the removal of the high voltages, it was found necessary to cut back the discharge emission current to levels ranging from 1.5 to 4.0 amperes. In the reapplication of the high voltages it was found imperative that the accelerator voltage always precede the screen voltage to prevent excessive electron backstreaming. The delay time between the reapplication of the two high voltages was 60 milliseconds with rise times of 60 and 280 milliseconds for the accelerator and screen, respectively.

A necessary condition for stable thruster operation is adequate component temperatures. With reduced beam and discharge emission current during recycle the component temperature changes, possibly leading to unstable control. To minimize thermal effects, the control logic provides for maintaining stable neutralizer operation and minimizing beam current overshoots. It was not found necessary to reduce the magnetic baffle current to insure reliable recycling.

Three different thrusters of the same design were successfully operated for many hours with the established control logic.

List of Symbols

V_A	accelerator voltage
V_G	coupling voltage
V_H	manifold isolator heater voltage
V_I	screen voltage
ΔV_I	discharge voltage
V_{KK}	cathode keeper voltage
V_{KT}	cathode tip heater voltage
V_{KV}	cathode vaporizer voltage
V_{NK}	neutralizer keeper voltage
V_{NT}	neutralizer tip heater voltage
V_{NV}	neutralizer vaporizer voltage
V_V	main vaporizer voltage
J_A	accelerator current
J_B	beam current
J_E	emission current
J_G	coupling to ground current
J_H	manifold isolator heater current
J_{KK}	cathode keeper current
J_{KT}	cathode tip heater current

J_{KV}	cathode vaporizer current
J_{MB}	magnetic baffle current
J_{MBN}	magnetic baffle field - ampere turns
J_{NK}	neutralizer keeper current
J_{NT}	neutralizer tip heater current
J_{NV}	neutralizer vaporizer current
J_{SCR}	screen current
J_V	main vaporizer current

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Table 1 Conditions Causing High Voltage Recycle

Parameter	Maximum Level, amps	Duration, sec
Screen current, J_{SCR}	3.0	0.5
Accelerator current, J_A	0.2	1.0
Accelerator current, J_A	0.4	0.1

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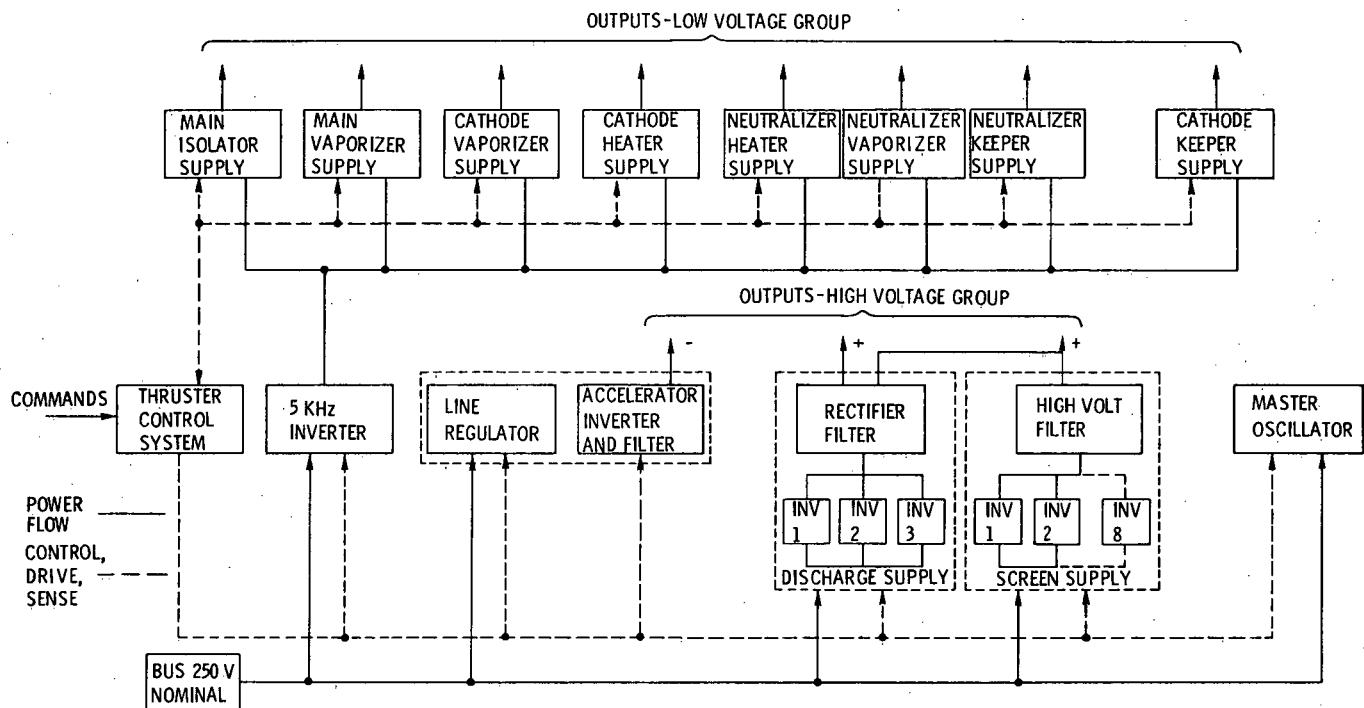


Figure. 1 - Power processor block diagram.

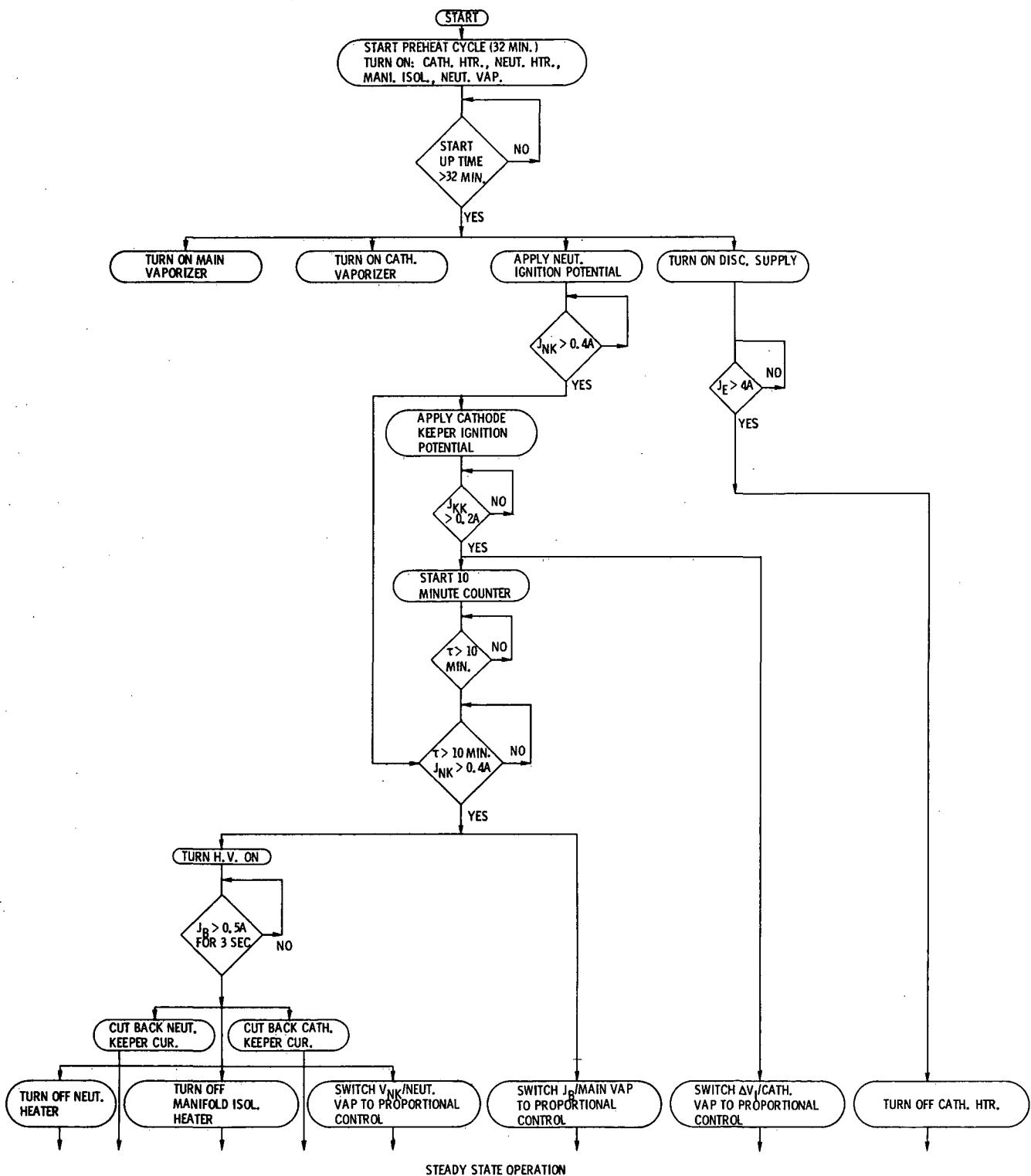


Figure 2(a). - Flow chart of automatic start up.

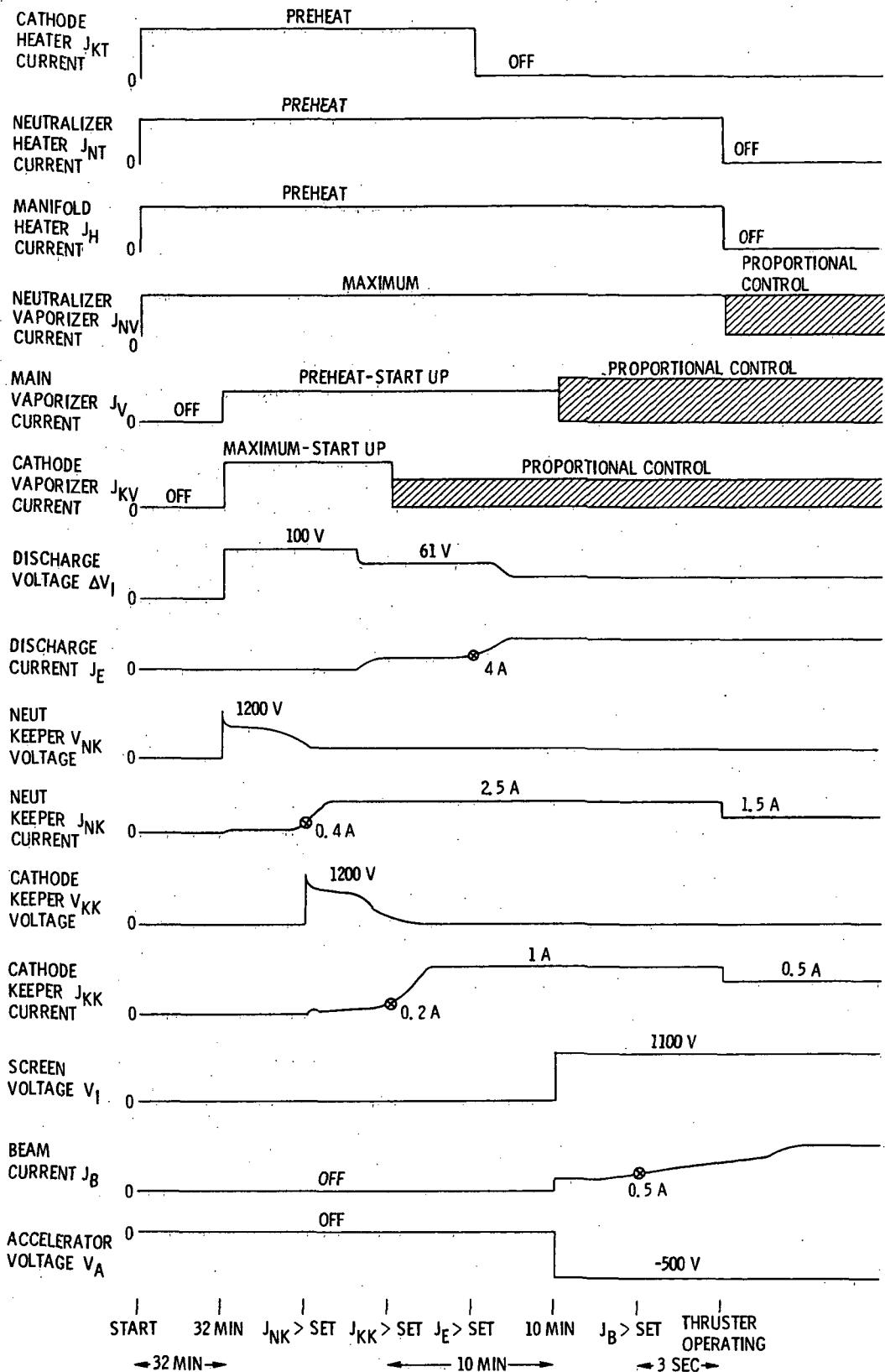


Figure 2(b). - Start up profile (time not to scale).

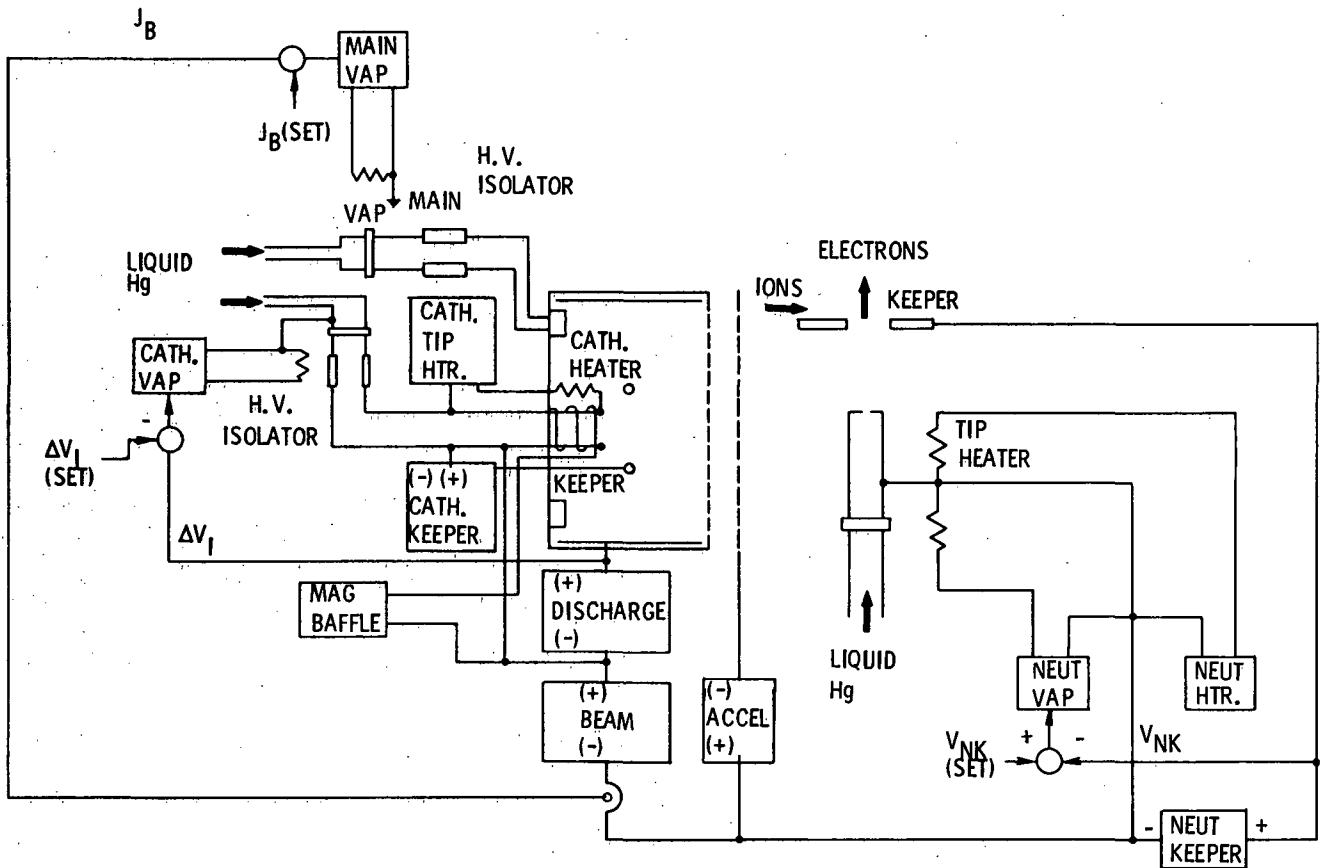


Figure 3. - Closed loop proportional control block diagram.

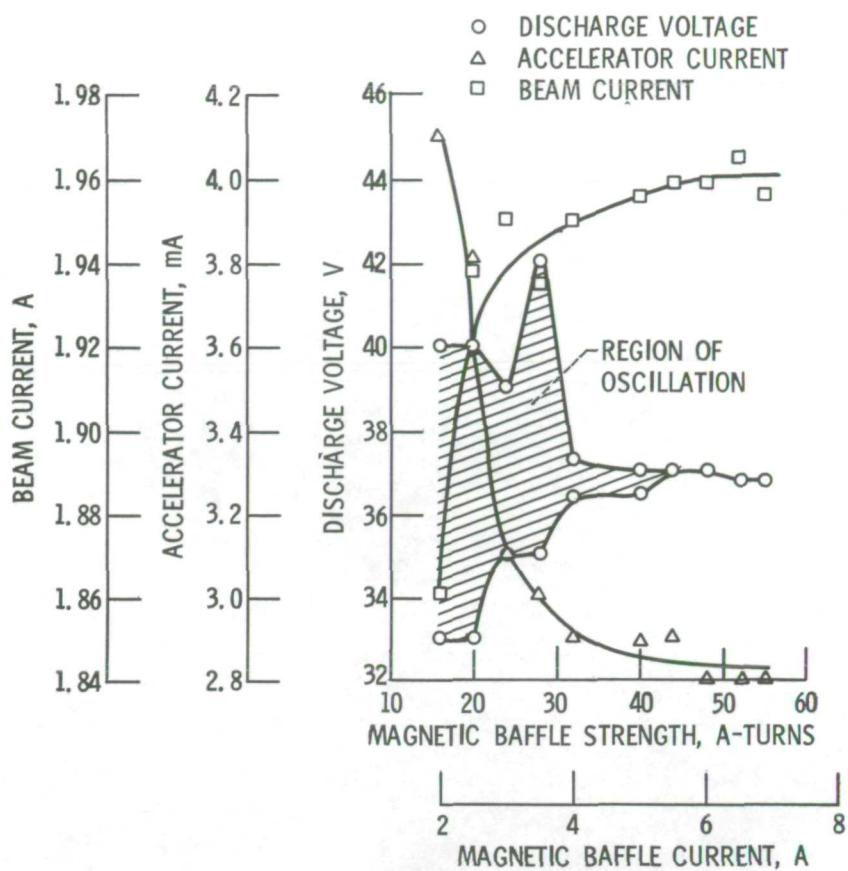


Figure 4. - Thruster performance at various magnetic baffle strengths.

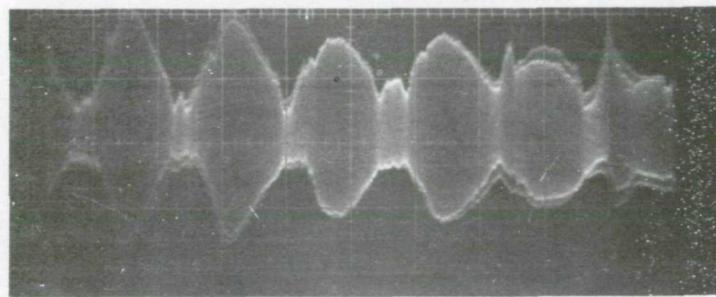
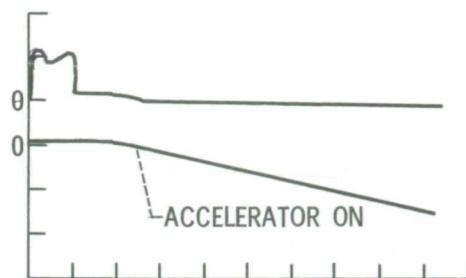
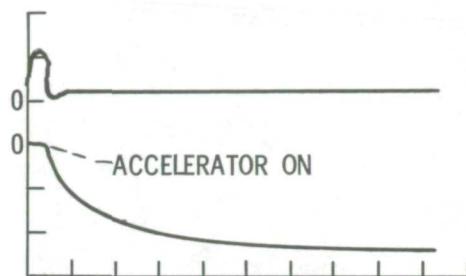


Figure 5. - Power source/power conditioner interactions. Bus current, 10 amp/div; time base, 5 msec/div.



(A) 20 mSEC/DIV.



(B) 100 mSEC/DIV.

Figure 6. - High voltage recycle when screen supply precedes accelerator supply. Upper-screen voltage, 100 V/DIV; lower-accelerator voltage, 200 V/DIV.

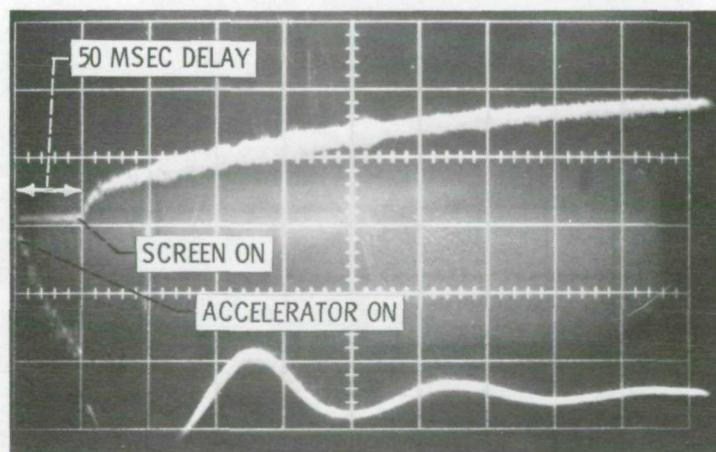


Figure 7. - High voltage reapplication to a thruster following an arc breakdown. Upper, screen voltage 500 v/div; lower, accelerator voltage 200 v/div; time base, 50 msec/div.

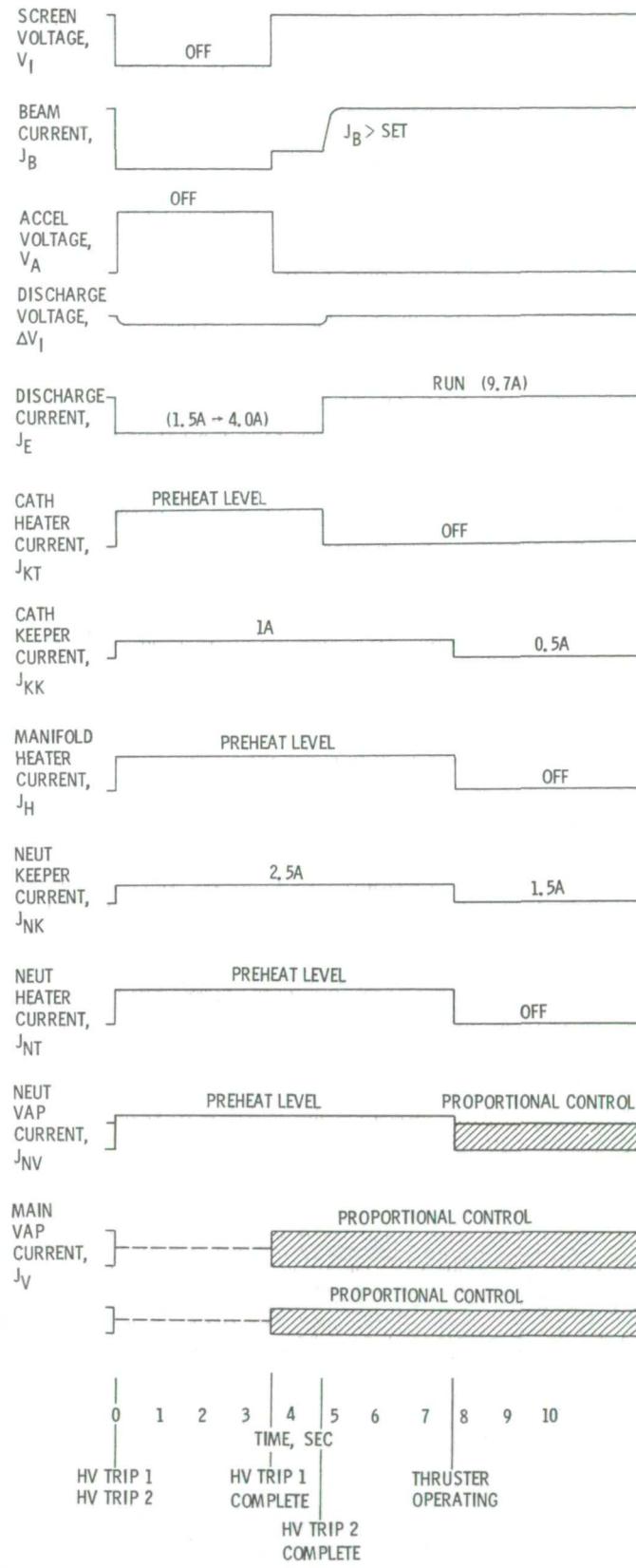
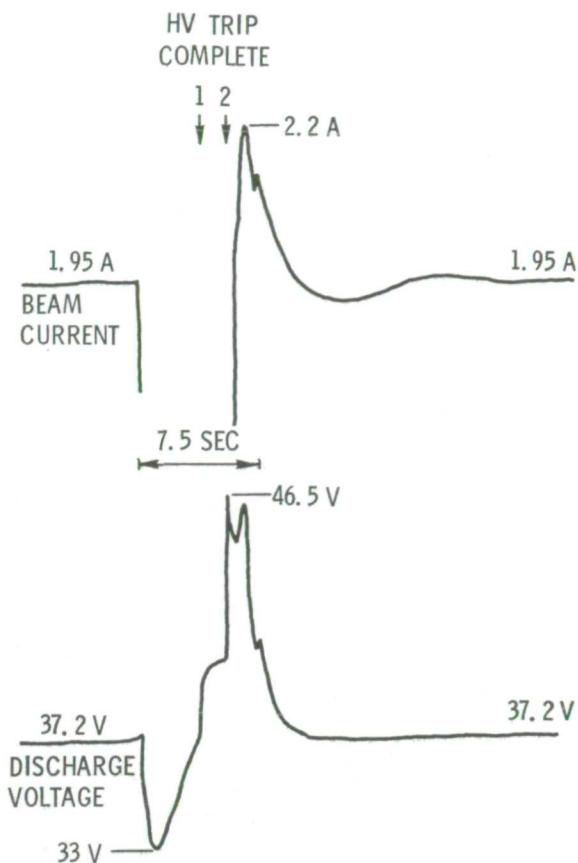
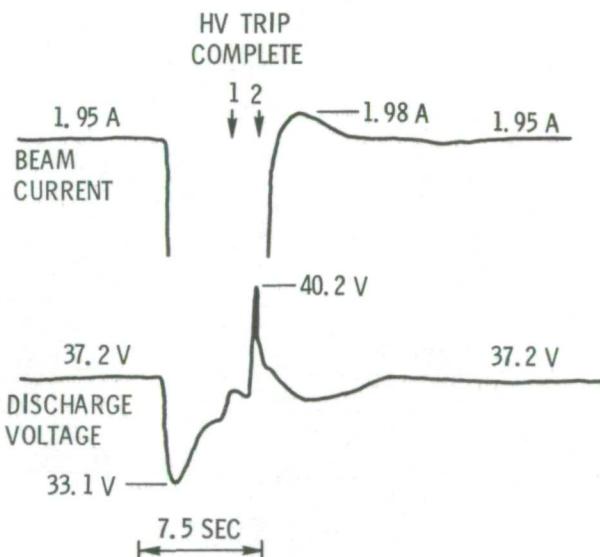


Figure 8. - Breakdown and recycle profile.

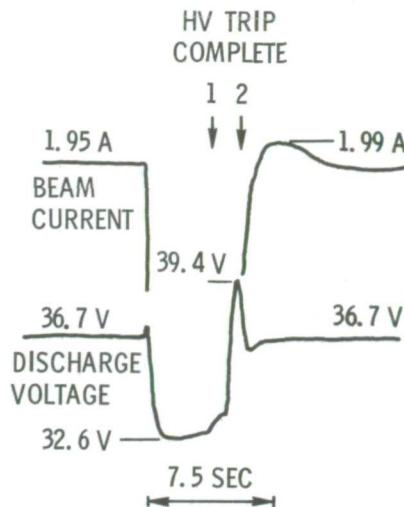


(A) CATHODE VAPORIZER IN CLOSED LOOP.

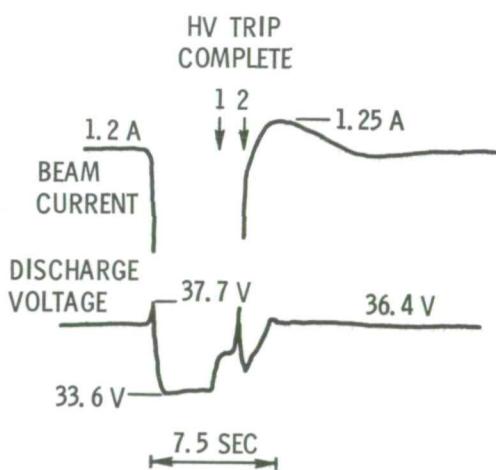


(B) CATHODE VAPORIZER IN CLOSED LOOP WITH REFERENCE VOLTAGE SWITCHED DURING HV TRIPS.

Figure 9. - Beam current, discharge voltage time profile following high voltage arc **main vaporizer** in closed loop.

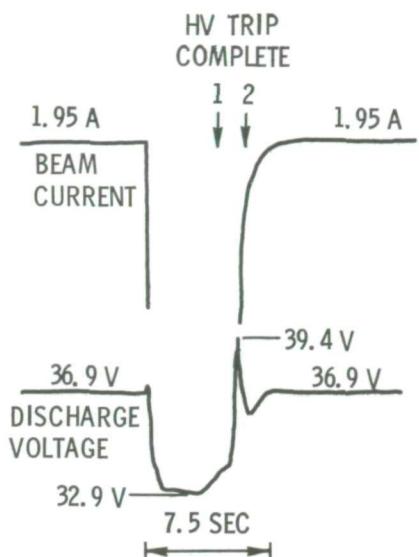


(A) BEAM CURRENT, 1.95 A.

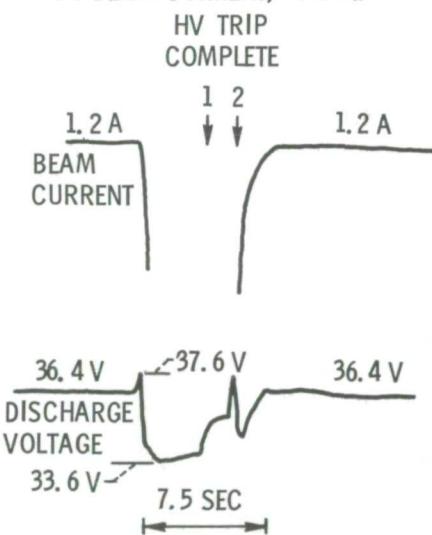


(B) BEAM CURRENT, 1.2 A.

Figure 10. - Beam current, discharge voltage time profile following high voltage arc.
Main vaporizer maintained in closed loop,
cathode vaporizer in closed loop with reference voltage switched during HV trip 2.



(A) BEAM CURRENT, 1.95 A.



(B) BEAM CURRENT, 1.2 A.

Figure 11. - Beam current discharge voltage time profile following high voltage arc. Main vaporizer in manual, cathode vaporizer in closed loop with reference voltage surtched during HV TRIP 2.

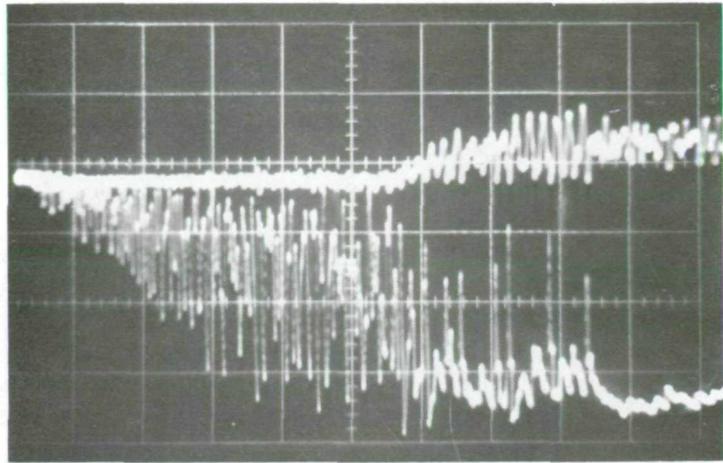


Figure 12(a). - Recycle high voltages with no additional impedance.
Upper, screen voltage 500 v/div; lower, accelerator voltage 200
v/div; time base, 10 msec/div.

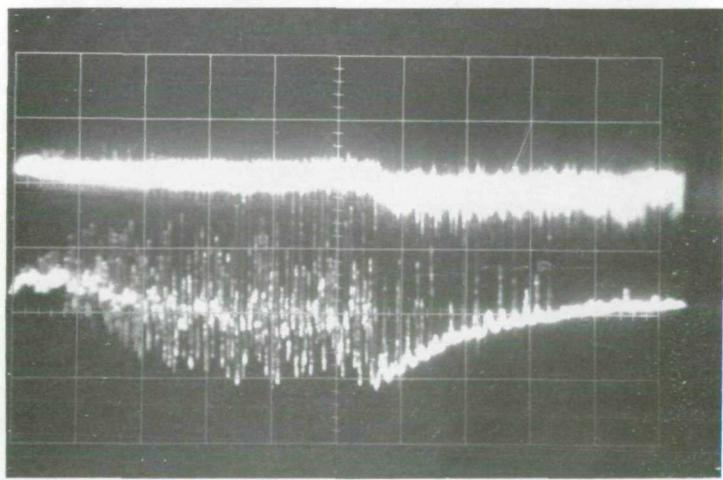


Figure 12(b). - Recycle grid currents with no additional impedance.
Upper, screen current 0.5 amp/div; lower, accelerator current
0.1 amp/div; time base, 10 msec/div.

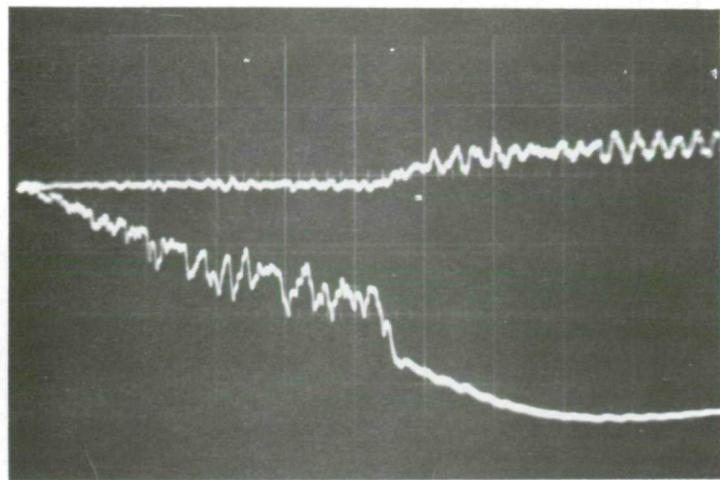


Figure 13(a). - Recycle high voltages with 0.5 mfd capacitors added.
Upper, screen voltage 500 v/div; lower, accelerator voltage 200
v/div; time base, 10 msec/div.

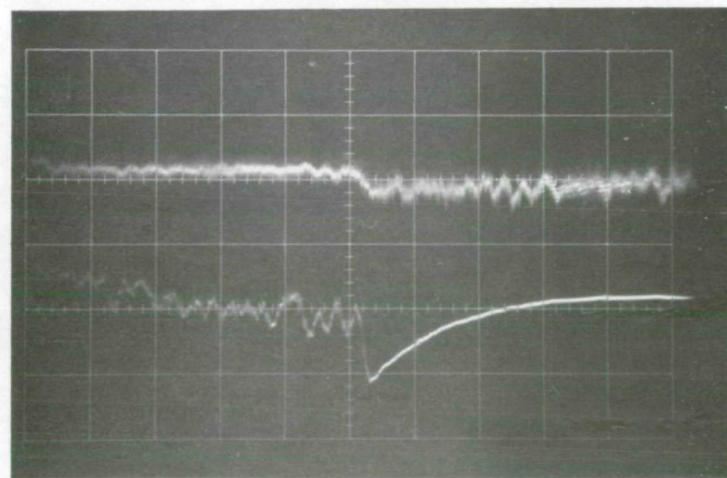


Figure 13(b). - Recycle grid currents with 0.5 mfd capacitors added.
Upper, screen current 0.5 amp/div; lower, accelerator current
0.1 amp/div; time base, 10 msec/div.

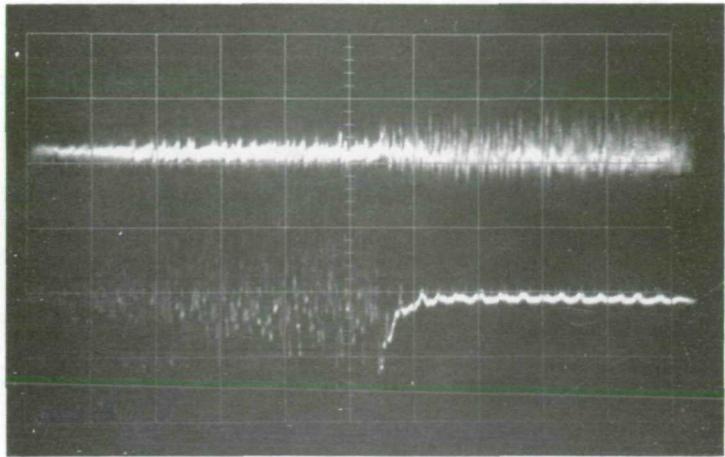


Figure 14. - Recycle grid currents at the thruster side of 0.5 mfd capacitors. Upper, screen current 0.4 amp/div; lower, accelerator current 0.1 amp/div; time base, 10 msec/div.